Examining the Potential of Low-Cost Virtual Reality for Low-Resource Learning Contexts

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Examining the Potential of Low-Cost Virtual Reality for Low-Resource Learning Contexts

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SUMMARY

We present a qualitative evaluation of a field deployment of the Google Expeditions Virtual Reality (VR) Toolkit at an after-school learning center for children from marginalized backgrounds in Mumbai, India. The lowering costs of VR technology make it especially attractive to study the feasibility of this and analogous toolkits in low-resource environments in and outside of India. Using a combination of interviews and observations, we demonstrate the feasibility of integrating VR into the classroom setting we study. We also illustrate the technical, social, and information dimensions that are critical for supporting this integration and present recommendations for deploying VR systems in other, diverse low-resource learning environments, seeking to motivate future examination of this space.

1 INTRODUCTION

Mobile penetration across the globe has grown rapidly in recent years, as a response to increasingly affordable access to network connectivity and lowering costs of devices worldwide. This has fundamentally transformed the nature of interactions between individuals from historically marginalized communities and information and communication technology (ICT). According to the World Development Report 2016, even among the poorest 20% of the developing world, 70 percent have access to mobile phones, more than those who have access to sanitation or electricity in their homes [23]. In addition to mobile access, over 40% of the globe has internet access and numerous state- and industry-supported initiatives are unfolding, aiming to connect those still unconnected [24, 25, 26]. With growing and more affordable access to ICTs across marginalized communities in developing parts of the world, there is reason to explore how we might leverage familiar technologies, or these increasingly ubiquitous ICTs, towards formal and informal learning opportunities.

Virtual Reality (VR) based systems have received much attention in recent years due to the engaging and immersive experience that they represent [27]. The consumer market has recently been flooded with VR viewers and software that offer participants opportunities to experience and own this technology at competitive rates. VR headsets have also become more affordable with the introduction of the Google Cardboard [28]. Headsets and platforms developed by the technology industry now support VR-enabled games, 360-degree videos and images, and the development of VR applications for widely-used mobile platforms such as Android and iOS.

The Human-Computer Interaction (HCI) community has engaged extensively with VR thus far. One of its focus areas has been to study participant interactions in multi-user virtual environments and explore the feasibility of VR for honing teamwork skills [15]. While there is some work on designing new VR interactions, this space is largely under-explored. Some HCI research has looked at designing virtual environments for students and integrating VR content into the classroom [9, 10]. However, there is much scope for further exploration.

We make a case for the need to develop specific infrastructures to facilitate VR platforms. We draw from the work by Cervantes et al. on designing support infrastructures for the use of laptops in a low-resource learning context [19]. The authors highlighted the technical, social, and organizational infrastructures, such as management, technical support, pedagogical support, and parental involvement needed to facilitate a mobile-laptop learning environment. Along with studying the design of the socio-technical infrastructures, we want to also address the ways in which content may be presented and situated in the VR context.

Our research examines the feasibility of integrating low-cost virtual reality technologies for supporting learning in low-resource settings, using a field study we conducted at Pragati[1], an NGO-operated after-school center in Powai, Mumbai (India) in June - July 2016. For this study, we procured the Expeditions kit [29] from the Google team in Mumbai, India. We first describe the research we build on. Following this, we provide details on our methodology and discuss our findings. Highlighting the potential of VR-based learning from a student and teacher perspective, we offer implications for integration of VR into low-resource learning environments. Our research contribution is to discover what happens in a low-resource educational context when VR is introduced. How do users in such a setting feel about VR? How do they plan to use VR to

[1] The name of the school and the names of all participants have been anonymized.

advance their educational goals? What are the challenges when VR is introduced into the class? What are the workarounds and solutions that users come up with?

2 RELATED WORK

A vast body of work in the HCI community examines the feasibility of various virtual and augmented environments [1, 2, 3, 4]. Extensive research has also been conducted in evaluating virtual reality systems in non-education contexts [5, 6]. Many HCI methods and probes have been utilized to conduct studies on the process of facilitating VR interactions. For example, Winterbottom and Blake [8] describe the process of creating a tool for designing and implementing interactions within virtual environments. They use a constructivist approach in their design tool. In 2004, Sutcliffe and Gault presented a heuristic method for evaluating virtual environment user interfaces [7]. They described inspection-based evaluation methods and illustrated it with three usability case study assessments.

In 2000, Alborzi et al. were among the first to design an augmented environment, in the form of room-sized ‘StoryRooms’ [9], that functioned as an interactive storytelling space and provided essential storytelling tools for children. They described their design philosophy, design process with children, and the current technology implementation for StoryRooms. This research was done at a time when a number of researchers had started to combine the power of computation with the familiarity of a child’s world. After that, in recent years, there has been a push for conducting research in the intersection of learning and VR, specifically in the use of VR in a learning context as well as in the the creation of learning content for VR-based platforms. For example, Bailenson et al. describe how virtual environments (VEs) enable the ability of teachers and students to use digital technology to strategically alter their online representations and contexts in order to improve learning [10]. Harrington discusses how we can best design interfaces to virtual and augmented reality technologies to support children in their independent quests for knowledge and acts of creation [11]. She provides an example prototype of a virtual environment that is intended to support scientific inquiry and artistic creativity for young children.

There have been many interventions that look into the 'gamification' of learning and designing group games in interactive virtual spaces for the growth and development of different social and cognitive skills [12, 13, 14] as well as interventions that seek to design mixed reality experiences. For example, Ellis et al. designed a collection of team-building games [15] situated in virtual environments by conducting participant observations in 3D virtual worlds. They utilized principles derived from social psychological theory and designed games that boosted emotional engagement and social interaction among participants. Also in 2016, Hu et al. studied the impact of physical and cognitive challenge on reported immersion for a mixed reality game [16]. They reported that building mental maps of the real, virtual, and sensed world is a cognitive challenge for novices, and this appeared to influence immersion. From their results, they proposed a model of immersion in mixed reality gaming for designers and researchers.

For many years, the HCI for Development (HCI4D) community has explored the feasibility of integrating mobile and internet technologies and content in diverse low-resource environments across the globe [17, 18, 19, 20]. As seen in the OLPC case [21], it is critical to explore whether teachers, students, and other stakeholders in the space would be able to incorporate a new technology into the setting. Following advice in Ismael's paper [20], and building on Warschauer and Ames [21] and Warschauer [22], we assess feasibility by going beyond monetary factors to examine social, technical, and information dimensions to inform future work in VR-based learning in low-resource settings.

With our research, we make a case for the need to develop specific infrastructures to facilitate VR platforms. We draw from the work by Cervantes et al. [19] on designing support infrastructures for the use of laptops in a low-resource learning context. The authors discussed that creating support infrastructures requires dealing with multiple interacting social and technical constraints. They highlighted the technical infrastructures, such as electricity, network, and tech-support infrastructures, and also social and organizational infrastructures, such as management, technical support, pedagogical support, and parental involvement. In our proposed research, we extend this work for the deployment of a low-cost VR system and also add a third dimension of information infrastructure design. Along with studying the design of the socio-technical infrastructures, we want to also address the ways in which content may be presented and situated in the learning environment.

3 METHODOLOGY AND TIMELINE

We conducted our research at an after-school learning center in Powai, a suburb near Mumbai, India inhabited by migrants from all over India. The center was founded 10 years ago by a doctor whose clinic was in the community, with the goal of providing free basic education to children from disadvantaged backgrounds. Classes take place in the morning (and afternoon) to cater to students attending public schools in the afternoon (and morning). These schools follow the state board's curriculum. Students receive lessons on topics covered in school, supplementary topics not in the state curriculum, and basic computer literacy.

At the time of the study, the center had 7 administrative staff, 12 teachers, 5 volunteers and 125 students (grades 4 to 12). Teachers were full-time employees who taught and managed a class. They were paid hourly based on their qualifications (high school diploma to a Bachelor of Education) and teaching experience (1 to 10 years). Volunteers were students from a nearby college who helped by providing one-to-one tutoring to students needing academic support. The center's facilities included 4 classrooms, one lab with 5 desktop computers and 1 printer, a Wi-Fi network, and 5 tablets. Two classrooms each contained a wall-mounted television and a desktop whose screen is projected onto the TV.

Study participants were a teacher named Meera (pseudonym), as well as all 6th-graders (8 girls and 1 boy) and 7th-graders (5 girls and 2 boys). Meera was responsible for teaching 6th- and 7th-graders General Knowledge, Geography, History and Science. She has a high school diploma and has been a teacher for 5 years. We worked with her upon the founder's recommendation, who commended Meera for her commitment to innovating on her teaching approaches. All fieldwork was conducted by the author, a native speaker of Hindi. Hindi was the language of instruction at the center. The data was examined by the author and other researchers and analyzed inductively to iterate on key themes. For our analysis, we took stock of our interview transcripts and field notes (recorded in Hindi and English). We analyzed this data using a grounded theory approach, as proposed by Charmaz [30], starting with memo-writing and building up these memos into a complete and cohesive analysis to distill themes. These were further refined through an iterative process that involved all researchers. We acknowledge here that the researchers have a fundamental leaning towards participatory action research, seeking to identify gaps that exist and might be addressed through the use of technology. We attempted to stay aware of our biases as we went about our research. Fieldwork took place as follows:

Phase 1: Formative work over 2 weeks in December 2015 and 2 weeks in June 2016. This phase included 60 hours of participant-observations over 12 visits; 20 semi-structured interviews with 15 students, teachers, and staff; 2 focus groups with parents and teachers; and 2 brainstorming sessions with teachers and staff. The goals were to gain a deep, situated understanding of the center's learning activities, as well as to establish the level of trust and rapport with stakeholders such that they see value in committing an adequate amount of time to co-designing and piloting VR-augmented lessons with us. In total, we observed 39 (and 33) class sessions among the 6th-graders (and 7th-graders) that Meera taught.

Phase 2: Co-designing the VR-augmented lessons lasted 1 week in June 2016, during which we worked intensively with Meera to co-design lessons that incorporated VR. In total, we co-designed VR-augmented lessons that spanned 6 lesson units, that can be further broken down into 28 academic topics for 15 classroom sessions (approx. 13 hours). The VR technology that we chose was Google Expeditions [29]. At the time of our study, it was the most inexpensive off-the-shelf option, worked under low bandwidth, and had a comprehensive suite of educational content (250 VR tours of landforms, natural ecosystems, landmarks, museums and cities, with more being developed). Expeditions runs on tablets and smartphones over a Wi-Fi access point that does not need connection to the Internet. To give the teacher more information about each tour when planning and teaching a lesson, the system allows her to view a write-up on each tour. She uses her tablet or phone as a remote control to select a tour, which is then downloaded wirelessly from her device to every student's smartphone. A student then views this tour virtually on her phone's screen. If she has a Cardboard viewer [28], she can insert her phone into the viewer to experience the tour more immersively as a 360-degree panorama, such that what she sees adjusts naturally as she turns her head.

Phase 3: Piloting the VR-augmented lessons with Meera over 2 weeks in July 2016 in 15 class sessions (6 with 6th-graders only, 6 with 7th-graders, and 3 with both). After every lesson, we iterated with Meera on her VR plans for subsequent classes. The Expeditions virtual tours were accessed using a Nexus 9 tablet (teacher), 12 Cardboard viewers (students), and 12 Nexus 4 smartphones (students). The phones were salvaged from recycling centers across Mumbai.

4 FINDINGS

We now present all our findings comprehensively, which highlight the early successes and challenges of integrating of the VR system in this context. We highlight the differences between VR and other mobile and tablet systems that have previously been deployed in similar low-resource environments. The distilled findings are published in [31].

4.1 Early Successes with VR Integration

The content available via Expeditions included 360-degree images or graphics of famous landmarks around the world, various land forms and animal ecosystems, virtual tours of cities and museums, among others [29]. The author worked with Meera to integrate this content into her lesson plan for two weeks. This process involved a broad-focus initial pass through different Expeditions ‘field trips’ to select content relevant to Meera's subjects. After a second, more focused iteration, the field trips were inserted into her lecture plans for the next two weeks. Meera actively engaged with the content, treating it as an extension of the knowledge presented in the subject topic. For example, the sixth graders had a history lesson on the Indus Valley Civilization that described the history of the place and the archaeological ruins that existed today. Meera selected the Machu Picchu trip as supplementary content to extend the general knowledge of the students and facilitate a compare-and-contrast exercise between two ancient civilizations.

Meera and the center's coordinator were very interested in integrating this content into the lesson plan. Both agreed that this new material, in VR format, added to the richness of the content presented to the students, and provided a more engaging classroom experience. This is what Meera said during the second week of this study:

"I loved working with the VR toolkit - especially because of the students' enthusiastic reactions! I want to use these viewers for at least 10-15 minutes every day, even if it is to show them new and informative content that is not related to the syllabus, simply because both the students and I learn so much from the content."

All participants (students and teachers) were familiar with VR technology through advertisements on television and billboards. As in the case of Kumar et al. [18] that used mobile phones, we found that students participated actively in class, displayed an interest in learning more about material in the syllabus and outside, and voiced their opinions in group discussions more often than they did before the introduction of the VR content.

Even before we brought up VR before the teachers, they brought it up with us. During prior fieldwork unrelated to this study, teachers had proposed the use of a VR-like '3-D' tool in their teaching. We noticed a desirability for using VR even before and during the use of Expeditions.

Teachers suggested use case scenarios for VR - such as in physics to visualize 3-D models of the solar system and in biology to visualize the real-time functioning of the respiratory system. Throughout the VR-integration process, teachers and students remained actively engaged with the product, both inside and outside the classroom. Students took charge of the maintenance of the kit and ensured the viewers were stacked up neatly before and after use and stored in dry locations. News of the VR kit reached the fringe members of the community and, very soon, local store owners and rickshaw drivers would visit to request for a demo. The fact that the teachers were willing to adopt this toolkit and do all the work required to appropriate it can be attributed to the general community's perception of virtual reality as an object of fascination and an advanced technology that they perceived was beyond their reach. Many senior students described their curiosity to learn about the technology behind the rendering of content in VR, and they wanted to explore whether they could generate new content which could be adapted for VR.

The access to the previously ‘out-of-reach’ VR technology further motivated teachers and students to fully appropriate this technology and push for efforts at personalizing the viewers. Students located the blue print of the Cardboard viewer (which is open-sourced on the Google website [28]), procured old cardboard shoe boxes and pizza boxes, printed out the cut-out blue print, and engaged themselves in groups to make their own VR viewers. The students and staff members used a plastic bottle to cut out lenses (which they learned to do from an online DIY tutorial), or they ordered some lenses online. This is what Meera said when she found out that students were making their own viewer.

“This is amazing! Can we make these at the center? We do not have enough funds to purchase the viewers (even though they are cheap). Just tell me what you need to make these and I will ensure that the students get these materials. I can also encourage the students to color and decorate their own viewers and make the viewers personal to each student. Most of the teachers and staff members own smart phones and we can use them. We could even add a logo of the NGO - this would be wonderful for the learning center as well.”

After making the viewer, students painted on the Cardboard, wrote their names, and accessorized their viewers with stickers and pieces of paper. Almost all the students at the learning center in all grades were involved in this `DIY movement', and this was not restricted to the students who belonged to our classroom study site. The new viewers created a sense of ownership among the students and, over the course of two weeks, they became more attached to the concept of VR content as an integral component of the classroom.

4.2 Obstacles to VR Integration

Participants faced many challenges with the hardware and usability of the VR system. Common issues faced by the students included overheating of the phones and, hence, the viewers. On the second day, two students refused to use the viewer because they were afraid that *"the Cardboard would explode if they looked at the VR content for more time because it had become so hot"*. The affordability and simplicity in design of the Google Cardboard viewer and the recycled smartphones brought with it battery duration constraints.

In terms of technical support, almost all groups of participants at the center became involved in the deployment and management of the VR system. The NGO staff members were tasked with ensuring that the phones were charged to full power before the start of the class every day. They struggled with this task because power sockets were limited and the center often encountered intermittent power cuts.

"We do not have so many sockets around to plug and charge so many devices. Also, I think it will be difficult to manage and use so many devices in the classroom if the teacher did not have 1-2 staff members constantly monitoring the class. I do not think we can provide that to all the teachers every day."

The presence of a support infrastructure in the form of a team of volunteers and staff members who were actively engaged in the deployment process played a major role in determining the success of the system. This is in strong contrast to mobile/tablet use in the class when no external support was necessary. We noticed that mobile/tablet content adoption was still easier than VR content adoption because participants were familiar with phones while they had never used VR before. Further, we noted that it was essential to foster a sense of ownership towards the VR equipment among the participants. By assigning specific roles and responsibilities to this group, we facilitated the inclusion of stakeholders (staff members) in the deployment and management of the toolkit.

Despite the enthusiasm that Meera and the students showed towards VR, Meera also struggled with the challenge of having a very small selection to work with. One workaround she suggested was to introduce a specific 'General Knowledge' time slot during class hours to give students a snapshot of the current news affairs and talk about topics that would *"expand their factual knowledge of the world."* This curriculum was modeled on the school's prescribed General Knowledge textbook and supported by the Expeditions field trips. Over two weeks, students saw field trips for the `Seven New Wonders of the World', Mt. Everest, scenes from the Moon landing, and more. Instead of adapting the VR content to the school curriculum, Meera was compelled to do the reverse:

"We definitely need more content. I would really love it if we could select any Science or Social Science topic in our syllabus and have a VR field trip to show the children. I would absolutely use something like this for 10 minutes every day in lecture. This kind of powerful visual aid is very useful for helping children improve retention. It is more engaging than tablet videos. Please get this kind of relevant content ASAP!"

Over two weeks, Meera said that she noticed students develop a `take-for-granted' attitude and an expectation that they would be using VR content in each lecture. As a result, students would tend to get impatient and focus less whenever the Cardboard viewers were not being used. Students and teachers requested that the content be more dynamic instead of simple pictures that were static in nature. They wanted to push the device's capabilities and watch videos and listen to audio content as well. Furthermore, because of the student's change in attitude towards the content presented in the class, Meera felt a compulsion to use VR content even when the available content did not connect with the topics for the lecture. She often had to struggle to fill the disconnect in the student's knowledge between the curriculum topic and VR content for that lecture, the latter of which was selected out of a compulsion (and, hence, was often disengaged with the main topic).

There were some challenges to the VR system that did not exist before, or did not manifest with mobile platforms for learning in low-resource contexts. Some students and teachers came in with apprehensions towards VR which were shaped by interactions with other people in the community and by constant exposure to popular media broadcasting services. One girl mentioned that her elder brother told her that using any VR headset would adversely affect her eyesight, and he cautioned her about using the device. Another student complained of eye pain:

"Sometimes my eyes hurt after 10 minutes. I felt like I was seeing two pictures at the same time and I had to adjust the phone inside the device many times but it kept slipping out. I wear spectacles and the specs pressed and hurt my nose. I was scared my spectacles would get crushed. Will this affect my eyesight?"

Many students were afraid to hold the device and walk with the viewer because they had developed an understand that VR technologies were very expensive. Most of these students linked the high cost of a piece of technology with fragility, and they were worried about paying for any damages to the device. This `fear of breaking the device' rose from the students' exposure to advertisements of high-end VR products that flooded the Indian consumer technology market. This understanding of expensiveness of the viewers was difficult to eliminate in the minds of the young children, despite a constant effort on this front by Meera. The fact that the viewer was made of Cardboard did not contribute to the cause in any noticeable way.

5 DISCUSSION

After VR was introduced into the lessons, students appeared to ask questions that reflected a deeper level of engagement with the topics targeted by the lessons. This outcome seemed to be facilitated by the affordance of representational fidelity that highly immersive VR has, such that students can view places and objects in the virtual tours with a higher degree of photorealism and fidelity compared to non-VR technologies. And it appeared that it was this fidelity that enabled students to take a closer, more vivid look at virtual places and objects that induced their deeper curiosity and questioning.

5.1 Implications of Low-Cost

In exploring the potential of VR as a ‘low-cost' technology in low-resource learning environments, we attained a nuanced understanding of costs involved - some more easily measured than others. With regards to monetary costs -- although the Cardboard was inexpensive and the students were able to make and customize their own, there was a need for mobile phones and Wi-Fi access as well. Not all learning environments in Mumbai, much less other parts of the developing world, have access to this technological infrastructure. On the other hand, for schools that do have the infrastructure, the additional financial overheads for integrating VR are low. It is worth noting that smartphones and Wi-Fi were both familiar to students coming from acutely marginalized backgrounds.

Additional costs were imposed on Pragati's resources. Support staff was needed for troubleshooting and to ensure that the technology was ready for use, though this may not be necessary once students are comfortable with the set up. Students were also afraid that they might drop and break devices; this fear waned with time. Finally, the enhanced engagement of students must be weighed against the increased burden on teachers to align this engagement with curricula and ensure that they were not less engaged or more distracted than before when they were not using VR in class. Once again, this may not be a concern once students are adjusted to a VR ‘routine’.

5.2 Agency in the Classroom

There were several concerns that arose in the course of our research, logistical and otherwise, but the teachers and/or students were equipped to address them. We emphasize the importance of engaging in co-design activities that maximize engagement of teachers, staff, and students towards identifying ‘solutions' to emerging ‘problems’, such as adapting available field trips to fit existing practices the way Meera did, leveraging VR to convert ‘free periods’ into learning opportunities, viewing shared access as a means for enhancing discussion, and more. This agency was key to the workability of VR in the classrooms we targeted, and highlighted the gaps that need to be addressed for VR to be successful.

5.3 Sustaining VR Interactions

The challenges mentioned above relating to integration of VR into low-resource learning environments can be categorized as short- and long-term challenges. We found that usability was a concern in the short term, since students complained that their eyes hurt and staff members were burdened with the task of ensuring that devices were charged and working, but these became less of a concern in the long run. To get through the initial difficulties, however, students and teachers must be able to nurture their desire and liking towards VR. We found that they were motivated to keep engaging with VR because they were able to appropriate it on their terms – that is, the teachers were able to enhance their teaching experience and the students were able to make and personalize their experiences. We believe that focusing on generating and leveraging this sense of ownership is likely to result in the sustained success of deployments. It is also critical to pay heed to teachers' requests for additional content relevant to the Indian context.

6 LIMITATIONS AND FUTURE WORK

During our six-week study, we encountered many research themes that could not be adequately studied in the short time frame. Some of these topics emerged from discussions with the participants while others were motivated by prior work in the VR and learning domain. We will briefly engage with some of these topics in this section and motivate future work in the space of designing low-cost VR platforms for learning.

VR provided an immersive experience for students and actively engaged them in topics they were introduced to. Examining the learning potential of VR content would take a longer assessment, but the feedback was promising. Some students consistently voiced a curiosity to learn about the technology behind underlying VR, and wanted to know if they could generate VR content. This interest could be tapped for greater engagement in future work. Further, news of the VR kit reached the fringe members of the community and local store owners and rickshaw drivers would visit to request for a demo. Future work might consider exploring the enrollment of these community members and the dissemination of diverse content which the community members might engage with.

Our literature review highlighted prior work that examined head mounted displays (HMDs) as better alternatives to flat-screen displays and future work could expand this research. While the Cardboard has become a popular low-cost alternative for presenting 3-dimensional stereoscopic content, existing applications for this and similar DIY cardboard-based VR HMDs have limited user-input capability, allowing mainly look-at control by head tilting. We extend the growing body of work conducted by the HCI community, which has explored various applications of motion sensors and finger contacts to create new interactions with the Cardboard and other mobile-based interfaces.

Finally, we seek to answer the question - what happens in the long term when the charisma of the VR viewers and platform have worn off? In this paper, we have summarized the findings of all our data collected in the six weeks and our findings have been very promising. There is a strong need to engage in a more comprehensive study over a long period of time and this is the primary focus of our future work.

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